# Research at Intel
## Investing in the Future

www.intel.com/research

**"You can't save your way out of a recession. To succeed in the long term, technology companies must continue investing in research, in good economic times and bad."**

Craig R. Barrett, *Chief Executive Officer, Intel Corporation*

Throughout Intel's history, when other corporations and government agencies reduced funding of computer science and information technology research, Intel maintained and sometimes increased funding levels. That commitment to research has led to a number of technology breakthroughs over the years, from dramatic reductions in transistor sizes to innovative manufacturing processes that take Moore's Law to new levels.

# Investing in the Future

## Expanding the Boundaries of Computing and Communications

Today, Intel's research efforts are expanding the boundaries of computing and communications technology. Our world-class research in silicon and advanced process technology and manufacturing has helped us to achieve and maintain our industry leadership position. Our microprocessor research—second to none in the industry—continues to advance the state of the art and extend Moore's Law. Our recent explorations into disruptive technology are driving toward a future of proactive computing, in which billions of embedded devices throughout the environment will anticipate our needs and sometimes take action on our behalf. We continue to push the limits of possibility.

## World Class Researchers

Intel's research initiatives are carried out by a highly specialized group of researchers around the world—some within our company, others in leading universities. Intel funds a substantial number of university research projects to ensure a steady flow of innovation into our industry. With the recent launch of the Intel Research Network of university labs—an innovative collaboration between industry and academia—we've strengthened our commitment to partnering with some of the best technology researchers in the world.

Translating research into products is one of Intel's greatest strengths. However far afield our explorations take us, the ultimate goal of our research is to influence product development—to enhance existing products in the near term and develop new products and usage models for entirely new markets over time. As a result, Intel researchers have the satisfaction of knowing their work may be translated into novel technologies and products that have a broad impact on the world in which we live.

For industry and academic researchers, these are exciting times to be a part of Intel's global research effort. In these pages, we will provide an overview of the research that Intel is sponsoring and conducting as part of our ongoing commitment to investing in the future of computing and communications.

“We are well on our way to producing a chip with one billion transistors.”

*Mark T. Bohr*

# Silicon, Process and Manufacturing Research

As technology research continues to bring productivity gains to businesses and consumers, the world’s appetite for faster, lower-cost, more powerful microprocessors will continue to grow. To feed that demand, Intel conducts world-class research in advanced silicon process technology and high-volume silicon manufacturing. Following are highlights of our research in these areas.

### Record-Breaking Processes

Intel recently introduced a 90nm manufacturing process that is second to none in the industry. Among other features, it includes a record-setting cache cell size of one square micron (a red blood cell is about 100 times larger). It also incorporates a new technology called strained silicon, which makes transistors faster, much as wider lanes speed the flow of traffic on a freeway.

**“We have already demonstrated our 90-nanometer logic process with the world’s highest density static RAM, containing 330 million transistors, using strained silicon technology. We are well on the way to producing a chip with one billion transistors.”**

Mark T. Bohr
Senior Intel Fellow,
Technology and Manufacturing Group
Director of Process Architecture and Integration

Our research goes beyond logic technologies, which are used to make our microprocessors and chip sets. We recently announced that we will extend our 90nm process to include passive components and a new type of transistor called SiGe (silicon germanium) HBT (heterjunction bipolar transistor). These new features will make our 90nm process suitable for high-speed communications applications, such as optical components. Intel will be the first company in the world to combine communications functionality with a 90nm process.

**“The TeraHertz transistor improves power efficiency, thereby enabling us to continue reducing circuit size while increasing chip performance.”**

Robert Chau
Intel Fellow, Technology and Manufacturing Group
Director, Transistor Research
Logic Technology Development

Our researchers have also developed an innovation in transistor design that helps to overcome a potential limit to Moore's Law: the power consumed and heat created by so many tightly packed transistors on a sliver of silicon. Using innovative structures and new materials, the so-called “TeraHertz” transistor can turn on and off over a trillion times per second, making possible extremely high performing and power-efficient devices.

Another innovation that Intel announced recently is the tri-gate transistor, which belongs to a class of 3D transistors that improve upon the planar transistors used in production throughout the industry today. The tri-gate transistor delivers very high “drive current,” which translates into high-frequency chips, while being highly manufacturable.

As part of our research, we are solving one of the problems related to manufacturing extremely small transistors—high gate leakage—by using materials called high-K dielectrics. Our research has shown that these new materials can reduce gate leakage by up to 10,000 times.

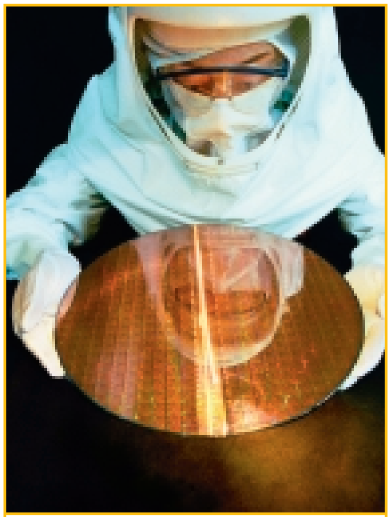
## Advances in Lithography

Intel is an industry leader in advanced lithography, the technology used to "print" intricate patterns that define circuits on silicon wafers. Intel led the industry transition to Deep Ultra-Violet (DUV) lithography. Today we are continuing this trend with strong investments in strategic 193nm, 157 nm and Extreme Ultraviolet (EUV) lithography, a technology breakthrough that will allow the patterning of lines below 50 nm dimensions, enabling higher-performance processors and the continuation of Moore's Law. We also helped to launch the EUV LLC, a consortium of technology companies, to develop EUV lithography.

EUV Lithography
Prototype Exposure Tool

## 300-millimeter Wafer Technology

Intel's latest chips are processed on another recent breakthrough, the 300-millimeter (12-inch) diameter silicon wafer. These wafers yield almost two and a half times as many chips as our earlier generation 200-mm (8-inch) diameter wafers.



"Our 300-mm wafers yield almost two and a half times as many chips as our previous generation of 200-mm wafers. These new wafers have lowered our manufacturing costs by 30 percent, and they are more environmentally friendly."

Robert A. Gasser, Jr.
Vice President,
Technology & Manufacturing Group
Director, Components Research

Our innovative "Copy Exactly" methodology for transferring technology and ramping new factories has been a big success. The methodology, which is being used to ramp 300-mm wafer technology, enables new fabrication facilities to begin producing with high yield as soon as they come on line.

## Innovations in Packaging

As processor performance increases, so do the demands on packaging of chips. Researchers face complex thermal, power delivery and signal integrity challenges, as well as the need to boost system-wide performance by providing faster connections to devices outside the chip. To meet these challenges, Intel is investing considerable resources in packaging-related research and development activities.

## Wireless Internet on a Chip

Intel is the leader in flash memory technology. With more than a billion Intel flash memory chips already shipped, we are developing a new process technology for combining a microprocessor, flash memory and analog communications circuits on a single chip of silicon. This "wireless-Internet-on-a-chip" technology could produce fast digital cellular data phones capable of operating for a month between battery charges and offering all the programmability and functionality of a handheld computer.

**For More Information**

To learn more about silicon, process and manufacturing research at Intel, visit http://www.intel.com/research/silicon/index.htm

“...we must develop a deep understanding of future computer applications and workloads.”

*Justin Rattner*

# Microprocessor Research

Intel’s investment in the future extends to industry-leading microprocessor research, including independent investigations as well as collaborative projects with academic and industry partners. Following are highlights of recent research within our five centers of excellence for microprocessor research: circuits, microarchitecture, system hardware, system software, and workloads.

**“To fulfill our mission of creating key technologies for future microprocessors and platforms, we must develop a deep understanding of future computer applications and workloads.”**

Justin Rattner
Senior Intel Fellow,
Enterprise Platforms Group
Director, Microprocessor Research

## Circuits

### 10GHz 32-bit Arithmetic Logic Unit (ALU)

To address the challenges of managing power consumption and heat dissipation, our researchers have developed a 10GHz 32-bit arithmetic-logic unit (ALU) running at room temperature. This circuit leverages advances in instruction scheduling, layout area reduction, performance optimization and leakage control.

**“Body bias techniques enable us to manage transistor performance, reduce leakage power, and get optimal performance for the power. They can even compensate for parameter variations to improve yields.”**

Shekhar Y. Borkar
Intel Fellow, Enterprise Platforms Group
Director of Circuit Research

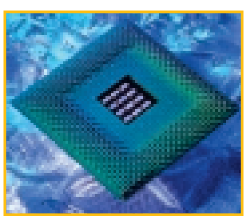
### Body Bias

We are optimizing circuit performance by dynamically adjusting the voltage applied to the body of the transistor, causing it to switch either faster or slower. Switching more slowly consumes less leakage energy. This technique enables us to ensure that all transistors are switching at the optimal rate.

## Microarchitecture

### Intel® Hyper-Threading Technology (HT Technology)

HT Technology is the first step in exploiting thread level parallelism (TLP) to increase performance and reduce power consumption. Researchers strive to identify TLP explicitly, in compilers and in binary translation, so that future microprocessors can be designed to take advantage of it.



### Multi-core and clustered microarchitectures

Another avenue we’re exploring to increase overall performance while reducing overall power requirements, is the concept of multi-core and clustered microarchitectures. Our unique approach focuses on optimized load balancing among CPU cores and clusters, through software and hardware mechanisms that dynamically examine the load, priority, thermals and criticality of processes.

**“We are exploring entirely new directions in microarchitectural research and design. Advances such as multi-core and clustered microarchitectures will enable us to continue delivering higher performance while reducing power consumption.”**

John Shen
Director, Microarchitecture Research

## System Hardware

### Increasing Integrity

One goal of our microarchitecture research is to increase the integrity of circuits operating under stressful conditions. To achieve this goal, we search for ways to reduce the number and impact of hardware and software failures and security breeches.

We are exploring the use of virtual machine technology to segment areas of the computer from one another. These segmentation techniques, at the microarchitectural level, allow tasks to be securely separated from one another, reducing the likelihood that a virus will propagate through the system or that a poorly written piece of software will result in system failure. Processors built using these techniques could bring a new level of stability and security to future systems.

## System Software

### Open Runtime Platform (ORP)

Java* and .NET* environments will fundamentally change the way software is developed and applications run on the platform. To help facilitate the transition to Java* and .NET,* we have developed an Open Runtime Platform (ORP). This tool makes advanced dynamic compilation and memory management technologies available to the research community, increasing the rate of innovation.

### Open Research Compiler

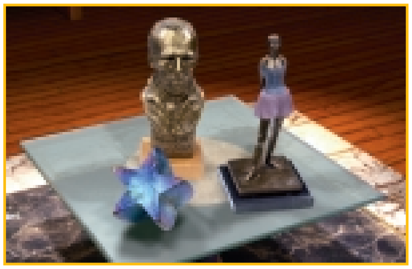
Intel is partnering with the Chinese Academy of Sciences in Beijing on advanced software compiler research to improve the performance and efficiency of the Intel® Itanium® processor family. In less than two years, the joint effort has produced an advanced compiler framework. The framework gives industry and academic researchers early access to open source software development tools and enables them to actively participate in Itanium processor family research efforts.

## Workloads

New workloads are creating demand for more specialized microprocessors. We focus on designing microprocessors that are optimized for two emerging technologies: computer vision and 3D applications.

### Computer Vision

To ensure that Intel microprocessors can accommodate computer vision (CV) applications within the next few years, we developed a software package, Open CV, that gives today's computers simple vision capability. We've made the software freely available to the research community, and we're using community feedback to gain a better understanding of the CV requirements of next-generation microprocessors. We are also developing novel techniques for high-precision quantitative nanofeature analysis and imaging.



Computer generated image made using Intel's light field mapping technology. The scene can be rendered at interactive frame rates on a PC.

### 3D Worlds

Rendering and manipulating realistic 3D objects in cyberspace requires sophisticated light mapping and a tremendous amount of computing power. To support emerging 3D technology, our research focuses on increasing the speed of Intel microprocessors and enabling them to handle 3D algorithms more efficiently. To advance this technology further, we are initiating a standards body to develop a file format for 3D objects on the Internet.

### For more information

To learn more about microprocessor research at Intel, visit http://www.intel.com/research/mrl/index.htm

# Exploratory Research

In addition to research that supports Intel's product roadmap, Intel sponsors and conducts exploratory research, focusing on emerging and disruptive technologies that will enable a future of proactive computing. This research is conducted internally and in university research labs.

**"We are moving toward a future in which billions of embedded, networked devices will anticipate our needs and sometimes act on our behalf. This proactive model of computing will liberate human beings from the need to interact one-on-one with all but a few computers."**

David Tennenhouse
Vice President, Director of Research

**Proactive Computing**

Today, computer science research is focused on an interactive model of computing, whereby people interact directly, one on one, with their computers. As we move towards hundreds and thousands of computers per person, this paradigm cannot scale; it would place far too high a burden on individuals.

The new environment will require an alternative, *proactive* model of computing. Under this new model, computers will anticipate our needs and sometimes take action on our behalf. We will continue to interact directly with a few of our computers, but the vast majority of them will be embedded deep within the physical environment, where they will capture and may act on data without the need for humans to be involved in the process. This proactive computing model will generate a new round of productivity gains and opportunities to enhance our quality of life.

To translate this vision of proactive computing into reality, we have identified seven key challenges that must be addressed, as illustrated on the following page.The first three challenges, starting with getting physical, involve creating and networking the billions of embedded sensor nodes. The next three challenges represent a disciplined approach to the application of statistically grounded machine learning, to enable the leap between interactive and proactive computing. The final challenge is *making it personal*—a challenge to the entire research community to sustain the cycle of personal empowerment that has been, and must continue to be, one of the most important contributions of computer science.

**"To deliver on the promise of proactive computing, we must understand how real people actually live, work, and play, and the differences across cultures and geographies. By understanding what people are doing now, we can better anticipate how technology might serve them in the future."**

Christine Riley, Ph.D.
Director, People and Practices Research

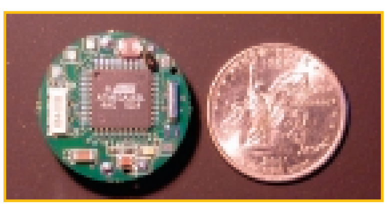
| Research Challenges | Focus of Research Projects |
| --- | --- |
| **Make It Personal**<br>Empowering individuals and addressing their concerns over security and privacy | • **People and practices**<br>• Security and privacy |
| **Closing the Loop**<br>Bridging the gap between anticipating and acting on needs—predictably, and under human supervision. | • Complex adaptive systems<br>• Agent negotiation<br>• Supply chain modeling |
| **Anticipation**<br>Creating proactive software that anticipates our needs and produces answers before they are required. | • Proactive health<br>• Distraction-free computing<br>• Labscape<br>• Machine learning |
| **Dealing with Uncertainty**<br>Using statistical modeling to deal with uncertainty inherent in the physical world. | • Bayesian networks<br>• Computational nanovision |
| **Planetary Scale Systems**<br>Developing software that works across a wide range of diverse platforms and networks. | • Novel storage systems<br>• **PlanetLab**<br>• Live databases |
| **Deep Networking**<br>Locally networking billions of embedded nodes; driving computing deeper into the infrastructure that surrounds us. | • Radio Free Intel<br>• **Sensor networks**<br>• Precision location |
| **Getting Physical**<br>Connecting computers directly to the physical world around them. | • Precision biology<br>• Novel sensors |

## People and Practices Research

Intel's People and Practices Research team, composed of social scientists, designers and engineers, strives to gain a deep understanding of how people live and work, and to translate that knowledge into concepts for technology that fit naturally into people's lives. Researchers travel the globe to conduct field investigations, interviewing and observing people as they go about their daily activities. In the process, they learn how people use technology, where it helps or hinders them, and what new computing applications might improve their productivity or the quality of their lives.

## PlanetLab: Enabling Technology for Planetary-Scale Services

A new kind of networked system is emerging in which nodes spread over much of the planet form a coordinated service, with content distribution networks and peer-to-peer applications being the first examples. We are working with the academic community to build an open, distributed laboratory in which to explore new planetary-scale services. For more details, visit www.planet-lab.org.



Tiny low-power wireless embedded platform ("mote")

## Sensor Networks

Intel is conducting and sponsoring several investigations into the deep networking of embedded systems. One internal project is exploring how inexpensive, ubiquitously deployed wireless sensors might be networked. Intel Research Berkeley is focusing on tiny low-power wireless embedded platforms ("motes") that incorporate flexible, open software systems and combine sensing, communication and computation. The lab is participating in a project to deploy sensor networks for habitat monitoring on Great Duck Island, Maine. Similarly, our People and Practices Research team is conducting an investigation into agricultural applications of sensor networks.

# University Research Labs

### Intel Research Network of Labs

Intel sponsors research conducted in five labs located near major research universities. Four of these labs operate under a bold new model of collaboration between industry and academia. These labs, wholly owned and funded by Intel, operate in a uniquely open fashion. Much of the research they generate will be published and shared widely.

In these labs, researchers investigate the disruptive technologies that will transform the vision of proactive computing into reality. Their work complements the exploratory research conducted within Intel's internal labs.

Currently there are four labs within the Intel Research Network, in Berkeley, Pittsburgh, Seattle, and in Cambridge, England. Each location provides facilities for up to 20 Intel scientists and student interns, and a similar number of faculty members and visiting members of the larger research community.

| Lab | Research Focus |
|---|---|
| **Barcelona**<br>Director: Antonio Gonzalez, Ph.D. | Microarchitecture and compiler research for power-aware and high-performance processors. |
| **Berkeley**<br>Director: David Culler, Ph.D.<br>Co-Director: Hans Mulder, Ph.D. | Extremely networked systems—the very large, the very small, and the very numerous |
| **Cambridge**<br>Director: Derek McAuley, Ph.D. | Networking, platform and development technologies that will enable proactive computing |
| **Pittsburgh**<br>Director: Mahadev Satyanarayanan, Ph.D. | Software for widely distributed storage systems |
| **Seattle**<br>Director: Gaetano Borriello, Ph.D.<br>Co-Director: Bill Schilit, Ph.D. | New technologies and usage models for ubiquitous computing environments |

### Intel Labs Barcelona

Intel also sponsors Intel Labs Barcelona (ILB), the company's first microprocessor R&D facility in Europe. In this new facility, Intel is conducting joint microprocessor research and development with the Universitat Politècnica de Catalunya (UPC), chosen for its world-renowned team of computer architecture researchers. Since work in this lab is directly transferable to Intel's microprocessor business, many of the research results will be proprietary. Nevertheless, some results are published in typical research forums, such as conferences and journals.

For more information

To learn more about the Intel Research Network of Labs, visit http://www.intel-research.net.

# A Commitment to Academic Research

To ensure ongoing technology innovation, Intel sponsors university research projects and curriculum programs throughout the world. Strong university relationships enable Intel to leverage the minds of some of the best faculty members and students who are, or will become, influential in our field. Today more than 250 Intel-sponsored research engagements are underway at universities throughout the world. (To learn more about Intel-sponsored university research, visit http://www.intel.com/research/university/ )

### Joining our Research Team

If you're looking for a chance to make your imprint on the future of computing and communications, Intel is the place to be. Career opportunities are available for qualified Ph.D.s and Ph.D. candidates in Computer Science and Electrical Engineering. For information about current research opportunities within Intel, visit http://www.intel-research.net/employment.asp or http://www.intel.com/jobs.

# Intel Leadership

Intel continues to provide the leadership required to ensure the growth and health of the computing and communications industry.

Craig R. Barrett
Chief Executive Officer

In response to reduced funding of technology research by traditional sources, in 1996 Craig Barrett founded the Focus Center Research Program (FCRP). FCRP is funded by IC manufacturers, their suppliers, and the federal government. Its objective is to establish technically focused, multi-university teams to engage in discovery research in areas which are potential bottlenecks for future development of the semiconductor industry. The ultimate goal is to ensure that the United States and U.S. semiconductor firms will remain at the forefront of the global microelectronics revolution.

Paul S. Otellini
President and Chief Operating Officer

Bringing computing and communications to everyone—any time, any place in the world—is the vision championed by Paul Otellini. He believes that Intel, with its strong heritage of integrated technology research and development, is uniquely positioned to usher in the next era of computing. The convergence of computing and communications will mean that all computers will communicate, and all communications devices will compute, delivering higher degrees of intelligence into a full range of devices, from cell phones and PDAs through notebooks, tablets, desktop PCs and servers.

Sunlin Chou
Senior Vice President
General Manager, Technology and Manufacturing Group

Sunlin Chou is chairman of the board of the EUV LLC, the industry consortium dedicated to bringing EUV lithography to market. The consortium has collaborated with the Lawrence Livermore, Sandia and Lawrence Berkeley National Laboratories to successfully demonstrate the commercial feasibility of EUV lithography. Chou believes that one day EUV lithography will be looked upon as one of the most important successes achieved through collaboration between the national labs and the semiconductor industry.

Patrick P. Gelsinger
Vice President
Chief Technology Officer

Pat Gelsinger wants to democratize technology, to make wireless communication inexpensive and ubiquitous. A key part of this vision, which he dubs Radio Free Intel, is that one day, every processor, every chipset, will have a built-in radio, forged in silicon. In this vision, every silicon device that Intel ships, every processor or chipset for a handheld personal digital assistant or cellular phone, a desktop or mobile computing device, will come enabled for communications over multiple networks, coupled with the capability for seamless, roaming connectivity. Radio Free Intel will usher in a new era of ubiquitous computing and communications.

Intel research and development is a decentralized worldwide network of researchers, scientists and engineers who are pioneering technology innovation and catalyzing cooperation within the computing and communications industry. With a network of over 7,000 technology professionals, Intel can focus on developing breakthroughs in a variety of areas, including silicon technology and manufacturing, microarchitecture and circuits, computing platforms, communications and networking, and software technology. For more than 30 years, the company's research and development activities have continually expanded the possibilities for enhancing people's lives and work through computing and communications.

For more information, visit http://www.intel.com/research



0103/ID/VM/3K

252200-001